INTERMITTENT SAND FILTRATION OF HOUSEHOLD WASTEWATER UNDER FIELD CONDITIONS[1]

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2.12

INTRODUCTION

Currently approximately 1/3 of the population of the United States is being served by on-site wastewater treatment and disposal systems (7). The most commonly used on-site wastewater treatment and disposal system is the septic tank-soil absorption system. Under proper soil conditions, the septic tank system serves as an adequate and economical method of wastewater disposal. However, the United States Soil Conservation Service estimates that 68% of the total land area in the United States does not have soils suitable for the installation of septic tank systems (9). In Wisconsin alone, 50% of the land area has severe limitations for soil absorption fields (9).

With this in mind, intermittent sand filtration of septic tank and aerobic treatment unit effluents was investigated as an alternative household wastewater treatment system. It was speculated that a substantial improvement in wastewater quality could be attained such that the sand filter effluent could be disinfected and discharged to surface waters. This is a treatment scheme that could be utilized where subsurface disposal is not practical or feasible.

EXPERIMENTAL PROCEDURE

Objectives

In an attempt to reduce the initial installation cost of the sand filter, it was desirable to keep the surface area of the proposed filters small, ranging from 50 to 100 ft^2. To accommodate the small surface area, hydraulic loading rates of wastewater applied to the sand filter were considerably higher (2-20 gpd/ft^2) than those recommended in the literature (0.5-3.0 gpd/ft^2). Thus, it was expected that periodic filter failure characterized by continuous wastewater ponding above the sand surface would occur. This would require some type of maintenance such as raking the sand surface, removing the top layer of sand or resting the

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[1] Information presented in this paper was obtained from the M.S. thesis of D.K. Sauer entitled "Intermittent Sand Filtration of Septic Tank and Aerobic Unit Effluents Under Field Conditions" (4) Department of Civil and Environmental Engineering, University of Wisconsin-Madison.

filter bed for some period of time in order to restore normal filter operation.

Failure of the sand filters was defined in most of the experimental work when the wastewater reached a ponded level of 12 inches above the sand surface. This provided a small wastewater reservoir above the sand which attenuated the hydraulic surge flows from the home. Some experimental work was also performed on sand filters which were operated only until ponding of the sand surface remained between dosings.

Evaluation of the intermittent sand filters was based upon the following criteria: (1) the effluent quality produced, (2) the variability in effluent quality, (3) the type and frequency of maintenance requirements, and (4) total annual costs.

Design of Installations

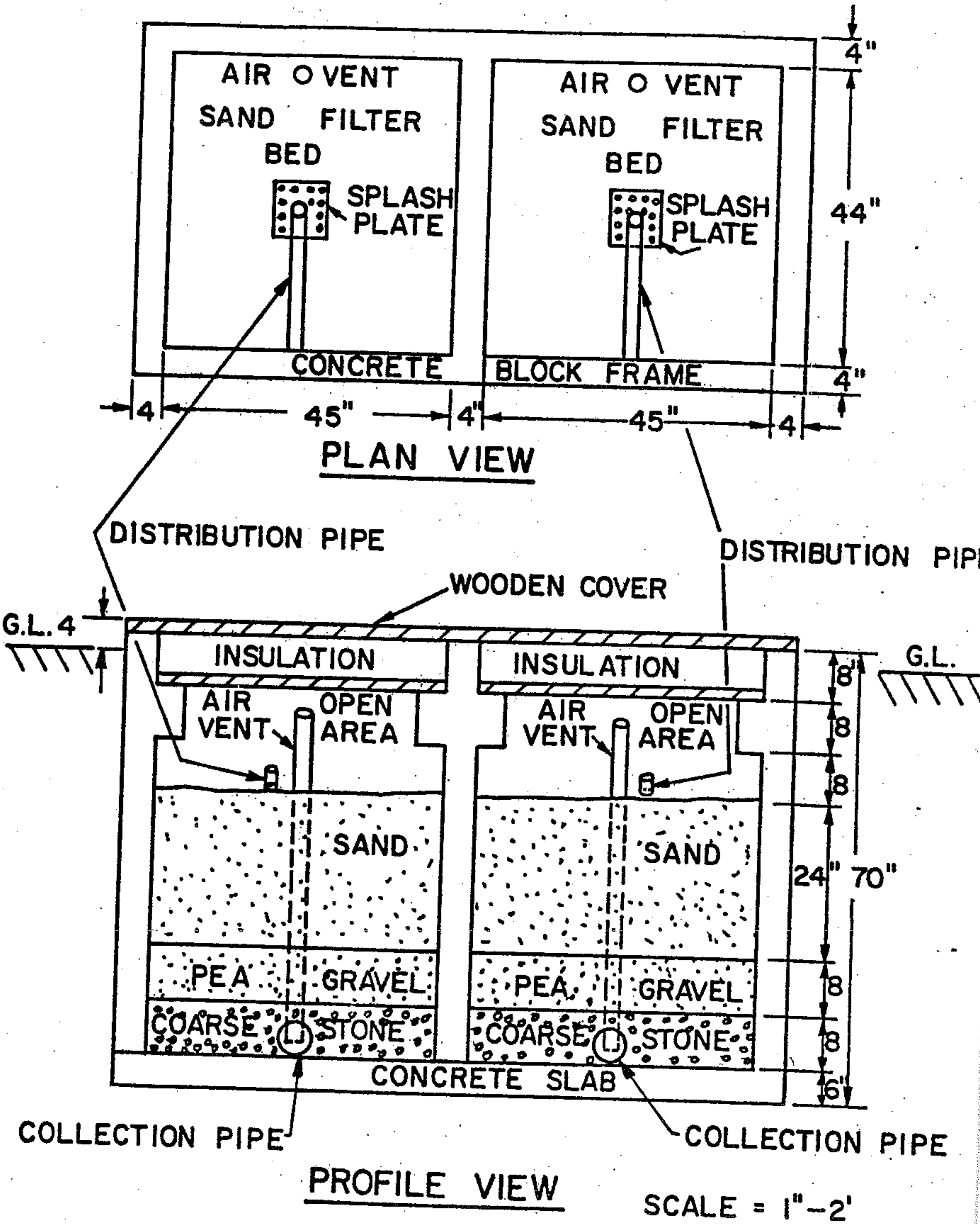
Intermittent sand filters were constructed and monitored at two home sites located on University experimental farms. Filters located at the Ashland Experimental Farm treated septic tank effluent while the filters at the Electric Research Farm treated activated sludge extended aeration effluent.

Two sand filters, each approximately 14 ft^2 in area and hereafter referred to as the east and west filters, were constructed at both home sites. The basins for the sand filters were constructed of concrete and concrete block, as shown in Figure 1. To prevent freezing problems, all but the top 4 inches of the basin were set below ground level. An insulated and removable wooden cover was fastened to the top of the filter basins. This cover prevented the accumulation of unwanted material on the sand surface, prevented odor and freezing problems and allowed easy access to the sand surface.

The collection system of the sand filter consisted of a 4 inch perforated pipe covered with 2 inch stone. The collection pipe was also vented to the top sand surface, as shown in Figure 1. The distribution system consisted of a 2 inch plastic pipe with an up-turned elbow located in the center of the bed. A splash plate was placed underneath the outlet elbow to reduce erosion of the sand surface. The effluent from the sand filters flowed by gravity through a dry-feed chlorinator and finally into a chlorine contact chamber. Hypochlorite in the form of tablets that contain a minimum of 70% free chlorine was used as the chlorine source. The filtered effluent dissolved the tablets in the chlorinator as it trickled past the tablets.

The chlorine contact chamber allowed sufficient time for the chlorine to disinfect the wastewater and also enhanced settling of suspended solids. The volume of the contact chamber was 114 gallons providing detention times ranging from 3 to 21 hours.

FIGURE 1 - INTERMITTENT SAND FILTERS



SCALE = 1"-2'

Operation

The sand filters were operated in parallel and contained 24 inches of locally available wash sand. The size of the sand used for the two home sites were considerably different (See Table 1). Cost of the sand media ranged from \$2 to \$9/ton.

Table 1. Sand Characteristics

	Effective Size	Uniformity Coefficient
Ashland Experimental Farm	0.45	3.0
Electric Research Farm	0.19	3.31

As shown in Figure 1, no gravel or soil cover was placed above the sand. The wastewater was applied directly to the surface of the sand and was allowed to pond above the sand and infiltrate through the bed.

Wastewater was applied to the sand filters 7 days/week and flow rates from the home were highly variable. Dosing the sand filters was controlled by the volume of wastewater generated each day. A wet well equipped with a submersible pump received the septic tank and aerobic unit effluent. After an accumulation of 40 gallons in the wet well, the submersible pump would activate and dose the filters. Intermittent sand filter parameters for the Ashland Experimental Farm and the Electric Research Farm are listed in Tables 2 and 3.

Sampling and Analysis

Sampling equipment was constructed such that 24 hour composite samples could be obtained from the septic tank, aerobic unit and intermittent sand filter effluents. The frequency of sampling ranged from once every 3 days to once every 3 weeks. Analysis of the samples included:

1. 5-day Biochemical Oxygen Demand, BOD_5
2. Chemical Oxygen Demand, COD
3. Complete solids analysis, TS, VS, TSS, VSS
4. Complete Nitrogen and Phosphorus, N, P,
5. Bacteriological analysis, Total and Fecal Coliforms, Fecal Strep, Total Bacteriological counts
6. Temperature, pH and residual chlorine

All of the above analysis were conducted according to Standard Methods for the Examination of Water and Wastewater (6).

Table 2. Intermittent Sand Filter Parameters at the Electric Research Farm

Applied Wastewater	Aerobic Unit Effluent
Period of Operation	Sept., 1973 through Feb., 1975
Filter Type	Open sand surface, vented under-drain
Operation of Filters	2 beds in parallel, continuously loaded 7 days/wk., flow rates of household
Surface Area of Filter	13.45 ft^2/each
Media	Commercially available sand, 24" depth
Media Characteristics	Effective size 0.19 mm, uniformity coefficient 3.31
Hydraulic Loading Rate	Ave. 3.8 gpd/ft^2
Filter Bed Failure Point	12" ponded wastewater on surface of sand
Maintenance Performed	West Filter - scraping the clogged surface sand, East Filter - removing the clogged surface sand
Frequency of Sampling	Average, once/10 days

Table 3. Intermittent Sand Filter Parameters at the Ashland Experimental Farm

Applied Wastewater	Septic Tank Effluent
Period of Operation	Oct. 1973-May, 1974; Aug. 1974-March, 1975
Filter Type	Open Sand Surface, Vented Under-drain
Operation of Filters	2 Beds in Parallel, Continuously Loaded 7 Days/wk., flow rates of household
Surface Area of Filter	13.75 ft^2/each
Media	Commercially Available Sand, 24" Depth
Media Characteristics	Effective Size 0.45 mm, Uniformity Coefficient 3.0
Hydraulic Loading Rate	14 to 42 gpd/ft^2 (Oct. 1973-May, 1974) Ave. 5.0 gpd/ft^2 (Aug. 1974-March, 1975)
Dosing Frequency	8-25 times/day (Oct. 1973-May, 1974) 4-13 times/day (Aug. 1974-March, 1975)
Filter Bed Failure Point	12" Ponded Wastewater on Surface of Sand, Beginning of Continuous Surface Ponding
Maintenance Performed	East Filter - scraping the clogged surface sand West Filter - removing the clogged surface sand East and West Filters - resting the clogged filter bed
Frequency of Sampling	Once/2-3 weeks

RESULTS

Effluent Quality and Variability

Septic Tank-Intermittent Sand Filter-Disinfection. Statistical analysis of the effluent quality data indicated that either normal or skewed (log-normal) distributions described the values obtained for different measured parameters. Coefficients of skewness were calculated and used to determine which distribution more nearly described the data. Almost all the parameters characterizing the effluents from the sand filters were log-normally distributed.

Analysis of the data for the septic tank-sand filter systems was performed over two distinct periods of time, from October, 1973 through May, 1974 - hydraulic loading rates 14-42 gpd/ft^2 and from August, 1974 through March, 1975 - ave. hydraulic loading rates 5 gpd/ft^2. Data presented in this paper gives the mean and the 95% confidence interval for selected parameters based upon the appropriate distribution (See Tables 4 and 6).

Phase I - October, 1973 - May, 1974. Referring to Table 4, the hydraulic loading rates were high from October, 1973 through May, 1974, however, almost 80% reduction of BOD_5 was obtained from the sand filters. Effluent BOD_5 values continually dropped as the age and maturity of the sand filters increased. A significant decrease in the BOD_5 was also accomplished in the chlorine contact settling chamber wherein BOD_5 was reduced from 22-25 mg/l to approximately 10 mg/l.

The Illinois Pollution Control Board effluent standards for discharge into intermittent streams are shown in Table 5. (3). Observing these standards, it is apparent that the effluent from the proposed sand filters loaded at the high loading rate will not meet these requirements.

Table 5. Illinois Pollution Control Board Effluent Standards for Discharge to Intermittent Streams

BOD_5 - 4 mg/l

TSS - 5 mg/l

Continuous Disinfection

Very little nitrification of the septic tank effluent by the sand filters was accomplished. This was mainly due to the high hydraulic loading rates (14-42 gpd/ft^2). Orthophosphate concentrations were consistently reduced 20-30% through the sand filters. Critical nutrient concentrations (nitrogen and phosphorus) discharged from sand filter systems will be largely dependent upon the dilution effect of the receiving stream. Due to this, approval of nutrient discharge to surface waters will likely be decided on a case by case basis.

Table 4. Effluent Quality Data (Septic Tank-Sand Filter-Disinfection System) October, 1973-May, 1974
Loading Rate 14-42 gpd/ft^2

		Septic Tank	East Filter	West Filter	Chlorine Contact
BOD_5 (Unfiltered) (mg/l)	Mean	120	25[1]	22	10[1]
	95% Conf. Int.	81-159	11-56	12-31	4-26
BOD_5 (Filtered) (mg/l)	Mean	97	20[1]	12[1]	7[1]
	95% Conf. Int.	63-130	8-53	8-20	3-19
COD (Unfiltered) (mg/l)	Mean	289	85[1]	77	76[1]
	95% Conf. Int.	207-371	53-136	48-106	49-120
TSS (mg/l)	Mean	45[1]	22[1]	13[1]	15
	95% Conf. Int.	31-64	11-43	5-32	8-22
VSS (mg/l)	Mean	33[1]	9	7[1]	7
	95% Conf. Int.	20-52	4-21	2-24	3-11
Ammonia-N (mg/l)	Mean	20.9	16.0	13.6	10.7
	95% Conf. Int.	15.0-26.9	10.7-21.4	7.6-19.7	6.4-15.0
Nitrite, Nitrate-N (mg/l)	Mean	0.3	1.0[1]	5.7[1]	2.1[1]
	95% Conf. Int.	0.2-0.4	0.3-3.2	2.6-12.5	0.6-7.1
Orthophosphate (mg/l)	Mean	10.9	5.9[1]	8.2	5.9
	95% Conf. Int.	8.4-13.5	4.1-8.3	5.0-11.4	3.9-8.9
Fecal Coliforms (#/100 ml)	Mean	5.4×10^5 [1]	9.8×10^3 [1]	2.7×10^3 [1]	61[1]
	95% Conf. Int.	2.7×10^5-10.7×10^5	1.8×10^3-51.6×10^3	0.5×10^3-15.2×10^3	5-794
Total Coliforms (#/100 ml)	Mean	2.0×10^6 [1]	2.3×10^4 [1]	1×10^4 [1]	203[1]
	95% Conf. Int.	1.3×10^6-3.2×10^6	0.4×10^4-13.1×10^4	0.2×10^4-5.5×10^4	10-4260

[1] Log-Normal Distribution
No. of Samples 7-15

Surface discharge recommendations for primary contact recreational waters for total and fecal coliforms are 1000/100 ml and 200/100 ml respectively (8). Observation of the data shows the coliform level was substantially reduced by the sand filters, but effluent levels of coliforms remained higher than the current discharge recommendations. Disinfection of the sand filter effluent by chlorination reduced coliform levels below the recommendations but chlorine residuals of 1.0 mg/l after 3-21 hours were consistently found. Zillich (10) reported that chlorine residuals as low as 0.04-0.05 mg/l were required before sub-lethal affects on fresh water fish were attained. Although good disinfection of the sand filter effluent was achieved by chlorination, lack of sufficient control of the rate of application of hypochlorite caused toxic levels of residual chlorine to be present in the chlorine contact chamber effluent.

Phase II - August, 1974 - March, 1975. The intermittent sand filters loaded at an average rate of 5 gpd/ft^2 effectively treated the septic tank wastewater as indicated in Table 6. Again, as the sand beds increased in biological maturity with time, effluent concentrations of unfiltered BOD_5 and TSS from the filters decreased constantly. Multiple dosing (4-13 times/day) of the relatively coarse sand, along with a lower hydraulic loading rate 5 gpd/ft^2, was felt to be the reason for the increased BOD_5 and TSS reduction. Concentrations of BOD_5 and TSS from the chlorine contact chamber effluent were 3 and 6 mg/l respectively. These values will meet the current surface discharge effluent standards for Illinois (Table 5).

Almost complete nitrification of the septic tank effluent was achieved by both sand filters after the sand filters became biologically mature. Maturity of the sand beds took approximately two weeks after initial wastewater application to the filters. Orthophosphate concentrations were again reduced 20 to 30% through the sand filters similar to that experienced from October, 1973-May, 1974.

Again, significant reduction of total and fecal coliforms were obtained through the sand filters. However, concentrations of total and fecal coliforms did not meet current surface discharge recommendations. Chlorination of the filter effluents reduced the coliform levels below the standards but chlorine residuals averaging 0.3 mg/l were found after 3-21 hours.

Aerobic Unit - Intermittent Sand Filter - Disinfection. Statistical analysis was performed on data collected from the aerobic unit-sand filter system between September, 1973 and February, 1975. The mean and the 95% confidence interval for selected parameters are shown in Table 7. The analysis of the west sand filter effluent was split into two time periods. From September, 1973 through October, 1974 the performance of the west filter was highly variable and inferior to that of the east filter.

Table 6. Effluent Quality Data (Septic Tank-Sand Filter-Disinfection System) August, 1974-March 1975 Loading Rate Ave. 5 gpd/ft²

		Septic Tank	East Filter	West Filter	Chlorine Contact
BOD_5 (Unfiltered) (mg/l)	Mean	123	9[1]	9[1]	3
	95% Conf. Int.	81-165	4-17	5-18	2-4
BOD_5 (Filtered) (mg/l)	Mean	87	6[1]	7[1]	2
	95% Conf. Int.	53-121	3-10	4-12	1-3
COD (Unfiltered) (mg/l)	Mean	280	52[1]	52[1]	32[1]
	95% Conf. Int.	173-387	33-83	29-91	21-48
TSS (mg/l)	Mean	48	6[1]	9[1]	6
	95% Conf. Int.	26-89	2-17	4-20	4-8
VSS (mg/l)	Mean	37[1]	4[1]	6[1]	4
	95% Conf. Int.	21-63	2-8	3-12	2-5
Ammonia-N (mg/l)	Mean	19.2	0.8[1]	1.1[1]	1.6
	95% Conf. Int.	14.7-25.0	0.2-2.8	0.4-3.6	0-4.4
Nitrite,Nitrate-N (mg/l)	Mean	0.3	20.4[1]	19.6[1]	18.9
	95% Conf. Int.	0.3	5.5-75.9	8.7-44.4	10.4-27.4
Orthophosphate (mg/l)	Mean	8.7	6.7[1]	7.1[1]	7.9[1]
	95% Conf. Int.	6.4-11.8	4.3-10.3	5.0-10.2	6.1-10.2
Fecal Coliforms (#/100 ml)	Mean	5.9×10^5 [1]	0.5×10^3 [1]	0.8×10^3 [1]	2[1]
	95% Conf. Int.	3.7×10^5-9.5×10^5	$.1 \times 10^3$-2.7×10^3	$.1 \times 10^3$-4.9×10^3	0.5-12
Total Coliforms (#/100 ml)	Mean	9.0×10^5 [1]	1.3×10^3 [1]	1.3×10^3 [1]	3[1]
	95% Conf. Int.	5.5×10^5-14.7×10^5	0.3×10^3-5.6×10^3	0.2×10^3-9.5×10^3	0.5-16

[1] Log-Normal Distribution
No. of Samples 7-14

Table 7. Effluent Quality Data (Aerobic Unit-Sand Filter-Disinfection System)
Loading Rate <u>Ave</u>.- 3.8 gpd/ft^2

		Aerobic Unit 9/73-2/75	East Filter 9/73-2/75	West Filter 9/73-10/74	West Filter 11/74-2/75	Chlorine Contact 9/73-2/75
BOD_5 (Unfiltered) (mg/l)	Mean	26[1]	4[1]	10[1]	2[1]	4[1]
	95% Conf. Int.	21-31	3-6	7-15	1-4	3-5
BOD_5 (Filtered) (mg/l)	Mean	9[1]	3[1]	6[1]	2[1]	3[1]
	95% Conf. Int.	7-12	2-4	4-9	1-3	2-5
COD_5 (Unfiltered) (mg/l)	Mean	82[1]	29[1]	43[1]	18	26
	95% Conf. Int.	70-95	23-36	33-57	11-25	21-33
TSS (mg/l)	Mean	48[1]	11[1]	37[1]	9[1]	7[1]
	95% Conf. Int.	39-58	8-14	25-56	5-15	5-9
VSS (mg/l)	Mean	33[1]	6[1]	15[1]	3[1]	4[1]
	95% Conf. Int.	27-41	4-7	10-22	1-5	3-5
Ammonia-N (mg/l)	Mean	0.4	0.3	0.4	0.6	0.4
	95% Conf. Int.	0-1.6	0.2-0.4	0.1-2.3	0-3.0	0.1-0.6
Nitrite, Nitrate-N (mg/l)	Mean	33.8	36.8	36.3[1]	21.9	37.6
	95% Conf. Int.	29.8-37.8	32.9-40.6	32.6-40.5	11.1-32.6	33.3-41.9
Orthophosphate (mg/l)	Mean	28.1	22.6	24.9	6.9[1]	23.4
	95% Conf. Int.	23.3-32.9	18.5-26.8	19.6-30.2	4.9-9.8	19.3-27.5
Fecal Coliforms (#/100 ml)	Mean	$1.9x10^4$ [1]	$1.3x10^3$ [1]	$2.8x10^3$ [1]	$1.8x10^2$ [1]	8[1]
	95% Conf. Int.	$1.4x10^4$-$2.7x10^4$	$0.9x10^3$-$2.0x10^3$	$1.8x10^3$-$4.4x10^3$	$4.8x10^2$-$7.1x10^2$	3-20
Total Coliforms (#/100 ml)	Mean	$1.5x10^5$ [1]	$1.3x10^4$ [1]	$1.8x10^4$ [1]	$3.4x10^4$ [1]	35[1]
	95% Conf. Int.	$0.9x10^5$-$2.6x10^5$	$0.8x10^4$-$2.2x10^4$	$1.2x10^4$ $2.5x10^4$	$1.3x10^4$-$8.4x10^4$	10-117

[1] Log-Normal Distribution
No. of Samples 10-51

Upon excavating the filter bed in October, 1974, numerous channels where short circuiting was occurring were found along the perimeter of the sand bed. It was concluded that the poor effluent quality of the west sand filter was due to poor construction technique. This was corrected in October, 1974.

Referring to Table 7, over 50% of the oxygen demand of the aerobic unit effluent was in the insoluble form. This organic fraction was due to the carry-over of biological cells from the aerobic unit. Conversely, almost the entire oxygen demand of the sand filter effluent was in the soluble form (indicated by filtered BOD_5). This indicates that the major reduction of oxygen demand by the sand filters was due to the straining and oxidation of the insoluble organic matter by the sand filter. (This is also supported by the fact that the crust layer on top of the sand surface contained over 70% volatile material.)

The effluent quality of the sand filter system in terms of BOD_5 and TSS concentrations of the chlorine contact chamber effluent was 4 and 7 mg/l respectively. This effluent quality will likely meet most surface discharge effluent standards mentioned previously.

The aerobic treatment unit produced a highly nitrified effluent over the experimental period. Concentrations of nitrate increased slightly through the sand filters due to the oxidation of organic and ammonia nitrogen. Orthophosphate concentrations of the aerobic treatment unit were reduced 20-25% by the sand filters. Lower concentrations of nitrates and orthophosphate from the new west filter (November, 1974-February, 1975) were due to a reduction in the nutrient concentrations applied to the sand filters over that time period.

Generally, a one log reduction in total and fecal coliforms was experienced from the sand filtration of aerobic unit effluent. However, effluent concentrations still remained higher than current standards mentioned previously. Chlorination of the sand filter effluent reduced total and fecal coliform levels below the surface discharge requirements. However, high residual chlorine levels were again found.

Maintenance and Servicing Requirements

Septic Tank-Intermittent Sand Filter. From October, 1973 through May, 1974, the intermittent sand filters receiving septic tank effluent were loaded at rates ranging from 14 to 42 gpd/ft^2. Due to the coarseness and uniformity of the sand (initial infiltration rates $\sim$ 150 gpd/ft^2), the sand bed hydraulically accepted the wastewater for 45 to 80 days before 12 inches of wastewater accumulated on the sand surface. The longest filter run was obtained on the initial experiment. Tables 8 and 9 summarize the operation and maintenance of the sand filters. A major conclusion reached from this phase of the study was that removing the top 4 inches of sand and replacing it with clean sand (77 day filter

Table 8. Operation and Maintenance of Intermittent Sand Filtration of Septic Tank Effluent

East Filter

Period of Operation Maintenance Performed	Length of Run (Days)	Type of Failure	Hydraulic Loading Rate (gpd/ft^2) and Quantity of Wastewater Applied to Filter (gal/ft^2)
Sept. 1973-December, 1973 Rested	80	12" Ponded Wastewater on Filter Surface	33.5 gpd/ft^2 2677 gal/ft^2
March, 1974-April, 1974 Replaced Top 4" Sand	45	12" Ponded Wastewater on Filter Surface	14.0 gpd/ft^2 630 gal/ft^2
August, 1974-November, 1974, Raked Top 4" Sand	98	1"-2" Ponded Wastewater on Filter Surface	5.07 gpd/ft^2 497 gal/ft^2
November, 1974-March, 1975 Raked Top 4" Sand	134	1"-2" Ponded Wastewater on Filter Surface	5.33 gpd/ft^2 714 gal/ft^2

Table 9. Operation and Maintenance of Intermittent Sand Filtration of Septic Tank Effluent
West Filter

Period of Operation Maintenance Performed	Length of Run (Days)	Type of Failure	Hydraulic Loading Rate (gpd/ft^2) and Quantity of Wastewater Applied to Filter (gal/ft^2)
September, 1973-December, 1973, Replaced Top 4" Sand	80	12" Ponded Wastewater on Filter Surface	33.5 gpd/ft^2 2677 gal/ft^2
January, 1974-March, 1974 Replaced Top 4" Sand	77	12" Ponded Wastewater on Filter Surface	14.0 gpd/ft^2 995 gal/ft^2
August, 1974-December, 1975 Replaced Top 4" Sand	142	12" Ponded Wastewater on Filter Surface	4.85 gpd/ft^2 689 gal/ft^2
January, 1975-March, 1975 Replaced Top 4" Sand	83	12" Ponded Wastewater on Filter Surface	4.89 gpd/ft^2 406 gal/ft^2

run) was a better maintenance technique than merely resting a failed sand filter (45 day filter run). It was also noted that operating at these flow rates and using the 12 inch ponding criteria caused the sand surface to virtually seal up. Infiltration rates dropped to as low as 0.12 gpd/ft^2. The top 10-12 inches of the surface sand were dark black in color, suggesting the accumulation of reduced materials such as sulfides. This is indicative of an anaerobic condition. A concentrated layer of sludge 1/8 to 1/4 inches in depth was also present within the top surface sand.

To obtain better control over the operation of the sand filters, float level sensors and a stage recorder were installed for the filter beds. From August, 1974 through March, 1975 the hydraulic loading rate to the sand filter averaged 5 gpd/ft^2. Length of filter runs ranged from 83 to 142 days. It was again noted that operation of the sand filter under the 12 inch wastewater ponding criteria caused succeedingly shorter filter runs. From August, 1974-March, 1975 the east filter was operated only until wastewater ponding on the sand occurred and remained between dosings. When this occurred, the sand surface was raked and put back into surface. This appeared to be a promising type of maintenance in terms of the length of filter runs as run lengths of 98 and 134 days were obtained. See Table 8.

It was observed that the degree of clogging by sand filters loaded at 5 gpd/ft^2 was less severe than the initial loading rates of 14 to 42 gpd/ft^2. Physical clogging caused by the suspended solids of the wastewater was felt to be the predominate clogging mechanism when the sand surface was not submerged. Biological clogging, due to microbial activity was felt to be responsible for the sand sealing occurring when the sand surface was submerged by wastewater. Allison (1) showed that under prolonged periods of submergence, the cause of soil sealing was attributed to microbial activity such as products of growth, cells, slimes or polysaccharides. He also showed that soil sealing was much more rapid when a soluble energy material was added to the water. The septic tank wastewater treated in this experiment contained over 90 mg/l of soluble BOD. Therefore, it may be concluded that the organic loading rate (L.B. of BOD) to the sand filters is very important in the rate and severity of clogging of the sand bed (2,5).

<u>Aerobic Unit-Intermittent Sand Filter</u>. From September, 1973 through February, 1975 operation of the intermittent sand filters was characterized by relatively low flow rates. Average hydraulic loading rates for each filter bed were 3.8 gpd/ft^2. Due to the small effective size sand used for these sand filters, initial clean sand infiltration rates were relatively low, 45 gpd/ft^2. Initial ponding of the wastewater on top of the sand surface occurred after only 35 to 40 days. Failure of the sand filters was defined as when the ponded wastewater had reached a level 12 inches above the sand surface.

The most significant characteristic of these experimental sand filters was the constant accumulation of suspended solids on top of the sand surface. After 114 days of operation, a 1/4 inch mat of suspended solids had accumulated on top of the sand surface. Failure of the sand filter occurred after 289 days. At this time the mat of suspended solids had become 3/4-1 inch in depth. Analysis of this mat showed that it contained over 70% volatile material. The sand immediately below the crusted layer was clean and contained less than 0.5% more volatile matter than clean sand. Raking the surface crust and removal of the crusted layer along with 1 inch of top sand with the replacement of the top 1 inch of sand with clean sand was felt to be the best types of surface maintenance for this type of sand.

Cost Analysis

An estimated cost analysis of the intermittent sand filter system is presented and is based on a survey of conditions experienced by contractors located in southern Wisconsin. Presentation of costs were made in the form of total annual cost for installation and operation of specified units amortized at 10% over a 25 year lifetime using 1975 dollars.

The components and flow diagram of the intermittent sand filter system is shown in Figure 2. The major components include: (1) septic tank or aerobic treatment unit, (2) pumping chamber onto the filters, (3) intermittent sand filters, (4) chlorination and final settling and pumping chamber.

The critical factors determining the cost of a sand filter are the amount of required surface area, the availability of quality filter sand and the frequency at which maintenance is performed. Sand filters with surface areas of 50 and 100 ft^2 are considered practical for an individual home and are used in the cost analysis.

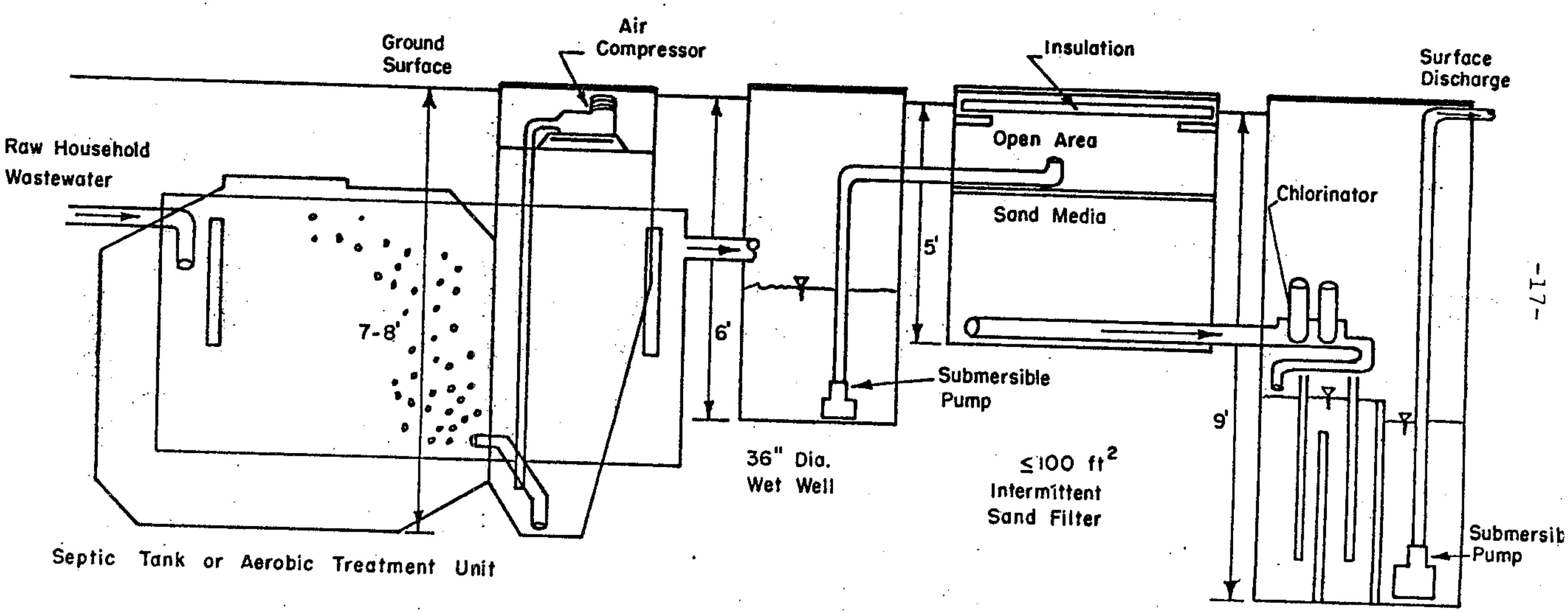
For the 50 ft^2 sand filter, maintenance consisting of alternately raking and replacing the sand surface once every four months was assumed necessary. Assumed maintenance for the 100 ft^2 sand filter consisted of alternately raking and replacing the sand surface once every 8 months. Since many variables affect the frequency at which maintenance is performed, only an estimate of the frequency can justifiably be given at this time.

A summary of four on-site wastewater treatment systems using intermittent sand filters is shown in Table 10.

Important conclusions drawn from the cost analysis include:

1. The total annual cost of a septic tank is approximately 1/4 the total annual cost of an aerobic treatment unit.

FIGURE 2
COMPONENTS AND FLOW DIAGRAM OF INTERMITTENT SAND FILTRATION SYSTEM



Design Flow 450 gpd

Table 10. Summary of Costs of On-Site Wastewater Treatment Systems Using Intermittent Sand Filters

System #1

Septic Tank	$ 58.82
Wet Well	43.89
Sand Filter, 50 ft^2	157.63
Chlorination and Settling Chamber	148.75
Total Annual Cost	$409.09

System #2

Septic Tank	$ 58.82
Wet Well	43.89
Sand Filter, 100 ft^2	246.31
Chlorination and Settling Chamber	148.75
Total Annual Cost	$497.77

System #3

Aerobic Treatment Unit	$243.24
Wet Well	43.89
Sand Filter, 50 ft^2	157.63
Chlorination and Settling Chamber	148.75
Total Annual Cost	$593.51

System #4

Aerobic Treatment Unit	$243.24
Wet Well	43.89
Sand Filter, 100 ft^2	246.31
Chlorination and Settling Chamber	148.75
Total Annual Cost	$682.19

2. The total annual cost of a 100 ft^2 sand filter is comparable to that of an aerobic treatment unit.

3. Systems No. 1 and No. 2 employing septic tanks and sand filters are more economically attractive than systems No. 3 and No. 4 employing aerobic treatment units and sand filters.

DISCUSSION

Some of the more important findings obtained from this study are listed below:

1. The combination of aerobic unit and sand filter treatment (loading rate 3.5 gpd/ft^2) provided a highly treated effluent in terms of BOD_5, COD and TSS. The effluent quality will meet most current surface discharge effluent standards.

2. Intermittent sand filtration of aerobic unit effluent at an average hydraulic loading rate of 3.5 gpd/ft^2 successfully operated for 9 months before surface sand maintenance was required. Raking the surface crust and removal of the crusting layer along with 1 inch of top sand with the replacement of the top 1 inch of sand with clean sand were felt to be the best types of surface maintenance for this type of sand (effective size 0.19 mm, uniformity coefficient 3.31).

3. Sand filtration of septic tank effluent at an average hydraulic loading rate of 5 gpd/ft^2 produced effluent qualities in terms of BOD_5 and TSS that will meet most surface discharge effluent standards. Complete nitrification of the septic tank effluent was obtained by the sand filter.

4. Length of filter runs for the septic tank-sand filter system (loaded at 5 gpd/ft) ranged from 3-5 months. Successful maintenance performed to these sand filters included:

   a. removing the top 2-5 inches of clogged sand and replacing it with clean sand,

   b. raking the top 2-5 inches of clogged sand without the addition of clean sand.

   Both maintenance techniques were performed after 1 to 3 week rest periods during which no wastewater was applied to the filters.

5. Total annual costs for treating and disposing of household wastewater using intermittent sand filter systems

ranged from $400 to $700. The range in costs is dependent upon the use of septic tanks or aerobic treatment units and the size and required maintenance of the sand filters.

REFERENCES

1. Allison, L.E., "Effect of Microorganisms on Permeability of Soil Under Prolonged Submergence," Soil Science, 63,(1947).

2. Clark, H.W. and S. Gage, "A Review of Twenty-one Years Experiments Upon the Purification of Sewage at the Lawrence Experimental Station," Fortieth Annual Report of the State Board of Health of Massachusetts, Public Document No. 34, (1909).

3. Hines, M., Regional Sanitary Engineer, Department of Public Health, State of Illinois, personal communication, (March, 1974).

4. Sauer, D.K.,"Intermittent Sand Filtration of Septic Tank and Aerobic Unit Effluents Under Field Conditions," M.S. Thesis, Department of Civil and Environmental Engineering, University of Wisconsin-Madison, (1975).

5. Schwartz, W.A., T.W. Bendixes and R.E. Thomas, "Project Report of Pilot Studies on the Use of Soils as Waste Treatment Media," In-house Report, Federal Waste Pollution Control Agency, Cincinnati, (July, 1967).

6. Standard Methods for the Examination of Water and Wastewater, American Public Health Association, American Waterworks Association and Water Pollution Control Federation, Thirteenth Edition, Washington, D.C., (1971).

7. Statistical Abstract of the United States, 1968, 80th Edition, Bureau of the Census, United States Department of Commerce, Washington, D.C., (1968).

8. Water Quality Criteria, Federal Water Pollution Control Administration, United States Department of the Interior, Washington, D.C., (1968).

9. Wenk, V.D. (1971), Water Pollution: Domestic Wastes. A Technology Assessment Methodology, Vol. 6, Office of Science and Technology, PB-202778-06, Washington, D.C.

10. Zillich, J.A., "Toxicity of Combined Chlorine Residuals to Freshwater Fish," Journal Water Pollution Control Federation, 44, (February, 1972).